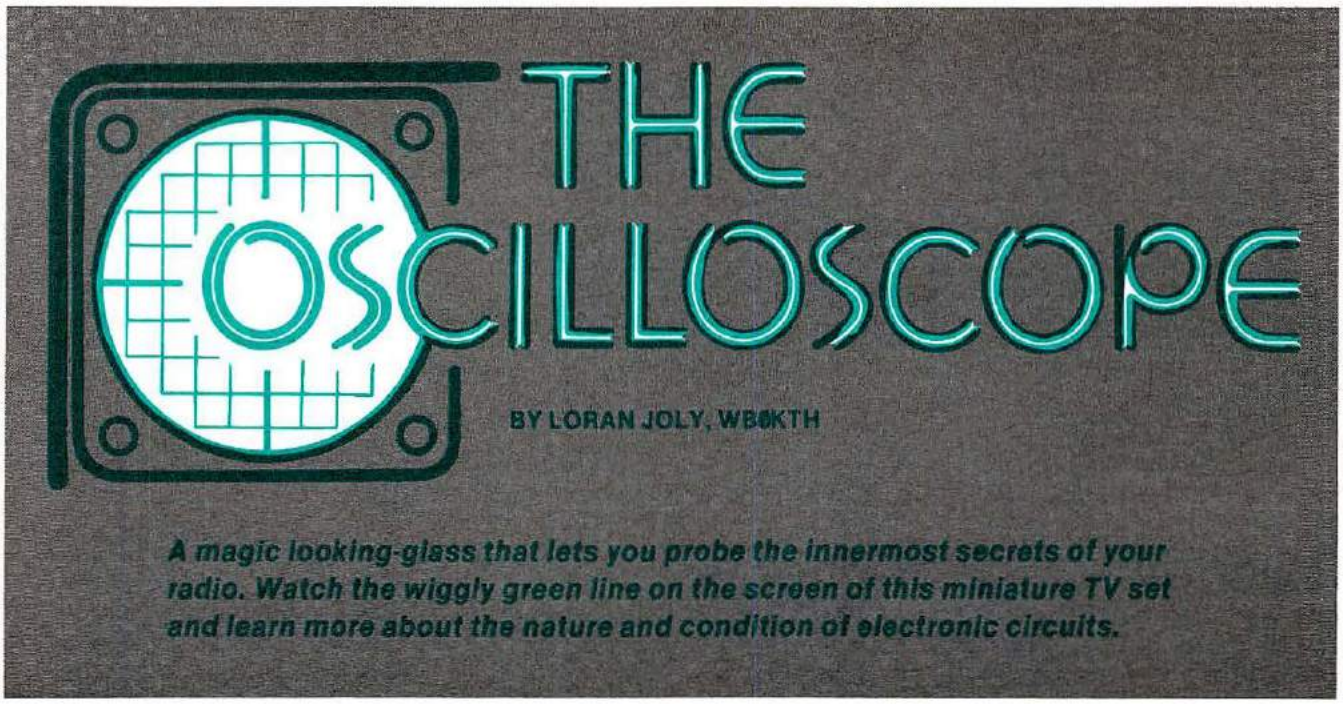

THE
OSCILLOSCOPE
BY LORAN JOLY, WB8KTH
A magic looking-glass that lets you probe the innermost secrets of your radio. Watch the wiggly green line on the screen of this miniature TV set and learn more about the nature and condition of electronic circuits.

An oscilloscope is one of the most useful pieces of test equipment available for the electronic hobbyist, builder, experimenter, and radio amateur. You can use it to display peak voltage against a time base, to measure peak-to-peak voltages, for signal waveform analysis, and — with the aid of a small outboard accessory — for testing semiconductors. Before we take a closer look at some of its details, let's first find out a little about what kind of animal the oscilloscope really is, and where it comes from.

An oscilloscope is related to your television set because both contain a cathode-ray tube capable of displaying information on its screen. A cathode-ray tube produces a stream of electrons that are focused or concentrated in a beam and accelerated to a phosphor screen placed on the inside surface of the tube's faceplate. The beam of electrons excites the phosphor screen and forms a glowing, greenish-white dot. The oscilloscope and TV set also have deflection circuits that act upon the electron beam and move it up or down and left or right, or in some direction that is a combination of these two basic directions. The moving dot is said to *sweep* across the screen and form a *trace* in the phosphor. Phosphors can be selected for their persistence, that is, the length of time they will glow after being excited by the electrons, but this is determined by the manufacturer of the cathode-ray tube and really doesn't concern us now.

The controls on an oscilloscope may seem bewildering at first, but once the basic purpose of each control is learned, the oscilloscope becomes a very simple instrument to use. Most 'scopes have the following controls, and some may have more:

Intensity — for adjusting the brightness of the trace on the screen of the cathode-ray tube (CRT).

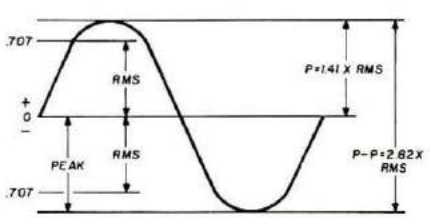


Fig. 1. Shows a typical sine-wave trace of one complete cycle, and illustrates the differences between peak-to-peak and rms voltages.

Focus — for adjusting the sharpness of the trace from a blur to a distinct line.

Vertical-Horizontal Position — for centering the trace on the screen.

Vertical Attenuator — for adjusting the strength of the signal presented to the vertical amplifier circuit in the scope. When set in the *X1* position, the signal is fed directly to the vertical amplifier. When set to X10, the signal is attenuated (reduced in strength) by a factor of 10. Some scopes have numerous attenuator steps.

Vertical Gain — for adjusting the amplification of the vertical amplifier circuit and the height of display.

Horizontal Selector — for selecting one of various horizontal inputs such as sawtooth sweep, 60 Hz source, or external synchronization, to be applied to the horizontal amplifier circuits.

Phasing Control — for adjusting the starting point of a trace to any desired point on the displayed waveform.

Coarse Sweep — for adjusting the range of sweep frequencies (coarse tuning) applied to the horizontal amplifier.

Vernier Sweep — for adjusting the frequency of the sweep voltage applied to the horizontal amplifier (fine tuning) within the range set by the *Coarse Sweep* control.

Inserting the Signal

When it is desired to observe a waveform representing an externally-generated signal, that signal is introduced through the *vertical input* terminal on the front panel of the oscilloscope. The horizontal-sweep frequency is adjusted to the frequency of the input signal by adjusting the *Coarse* and *Vernier* sweep controls, until the waveform trace is stabilized on the screen. Example: A single sine wave, that is, one complete cycle.

Expensive oscilloscopes have a desirable feature known as *triggered sweep*, meaning that the input pulse or signal starts and stops the sweep. Triggered-sweep oscilloscopes have precisely-calibrated vertical and horizontal gain controls to facilitate time and voltage measurements, and usually have a square-wave voltage terminal for calibration purposes.

The input signal passes through a *blocking* capacitor on its way to the vertical amplifier circuit of the oscilloscope. The capacitor may be switched in or out of the signal path. If the capacitor is switched in, any dc voltage present on the input signal will be prevented from appearing on the displayed trace. If the capacitor is switched out, a trace representing the ac voltage, as well as the dc voltage, will be displayed on the screen.

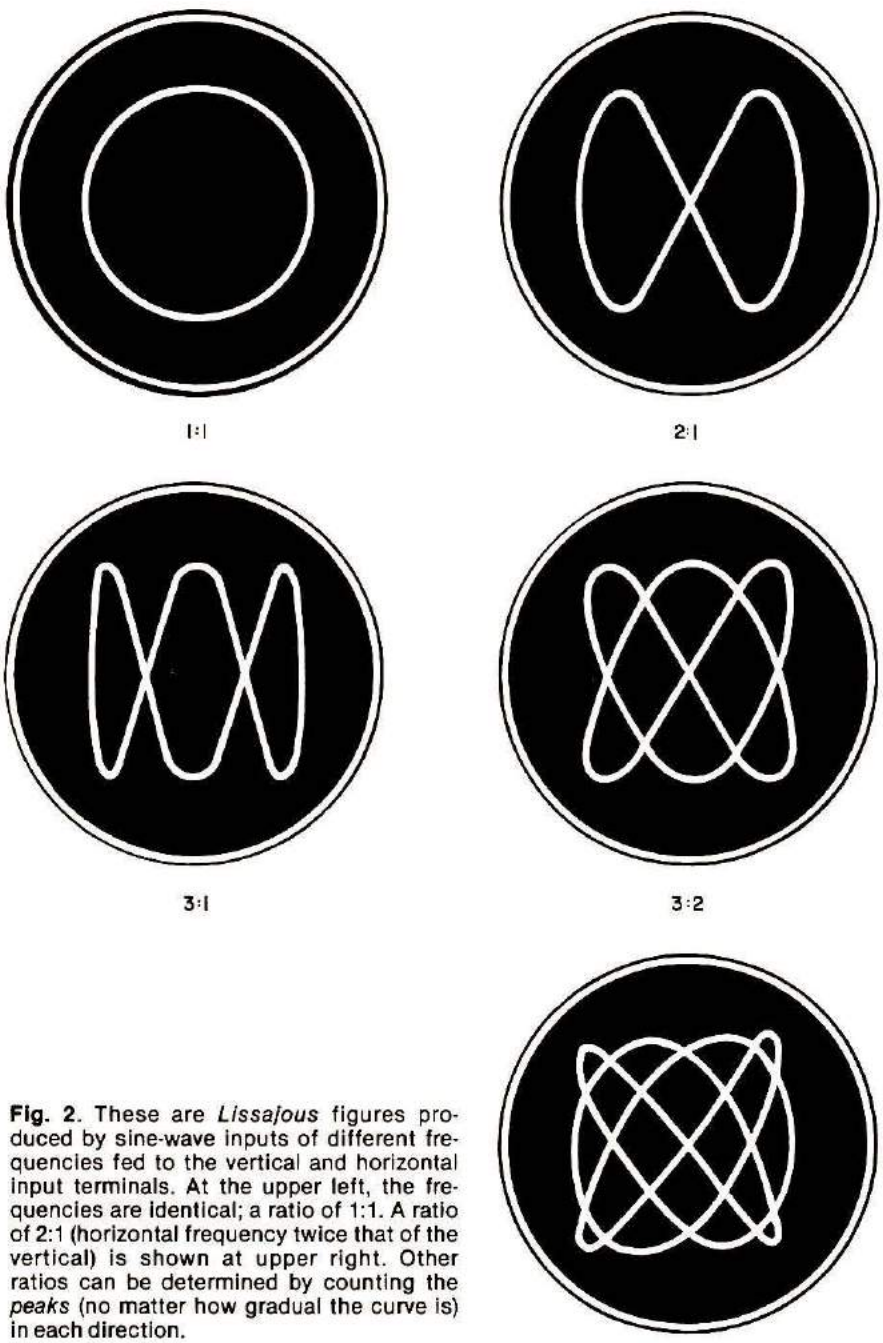


Fig. 2. These are *Lissajous* figures produced by sine-wave inputs of different frequencies fed to the vertical and horizontal input terminals. At the upper left, the frequencies are identical; a ratio of 1:1. A ratio of 2:1 (horizontal frequency twice that of the vertical) is shown at upper right. Other ratios can be determined by counting the *peaks* (no matter how gradual the curve is) in each direction.

Using the Oscilloscope

The active ham or experimenter can find a number of different and valuable uses for the oscilloscope. For example: Voltage measurement. The oscilloscope can display dc, sine wave, square wave, sweep, and synchronizing voltages. The sine wave voltage is used for calibrating the scope for peak-to-peak (p-p) voltage measurements. **Fig. 1** shows the relationship between *peak* and *rms* voltage.

Rms voltage is usually read with the aid of a meter, and *peak-to-peak* voltage may be determined by multiplying the rms value by 2.82. Therefore, the common line voltage found in the home will read 117 volts ac on the meter, but is actually 330 volts peak-to-peak. Having calibrated the oscilloscope by adjusting the sine waveform trace to the proper height on the screen, other voltages may be displayed and accurately determined.

To calibrate the *vertical gain* control, hook up the low

voltage (output) side of a 117- to 6.3-volt ac transformer to the vertical input terminal of the oscilloscope. Since the p-p value of 6.3 volts rms is approximately 18 volts (actually 17.77 volts), adjust the *vertical gain* control until the trace pattern occupies a vertical height of 18 divisions on the plastic grid that overlies the face of the cathode ray tube. This grid, or *reticule*, is divided into tenths of an inch (2.54mm), just for this purpose. As long as the vertical gain control is left at this calibration point, each mark on the plastic reticule will represent one volt. Now you may apply any ac voltage up to 6.3 volts rms to the vertical input terminals of the oscilloscope, and accurately "read" its exact peak-to-peak value. The same procedure may be followed with other voltages by first calibrating the 'scope to a known voltage in the manner described above.

Frequency measurement

Lissajous figures are used to measure frequency. A Lissajous figure is a waveform trace appearing on the screen as the result of applying sine wave signals to both the vertical and horizontal input terminals of the oscilloscope. For example, a known, standard-frequency, ac voltage, such as the 60-cycle power frequency, is applied to the horizontal amplifier terminals, while an unknown-frequency ac voltage is applied to the vertical amplifier terminals of the oscilloscope. The resulting waveform displayed on the screen will be a symmetrical pattern of interlocking traces whose dimensions and appearance are the result of the ratio between the horizontal and vertical input frequencies. By counting the loops on both sides of the patterns, you can find the ratio and, therefore, determine the unknown frequency. **Fig. 2** shows a few patterns that you may encounter, and how to count the loops to find the ratio.

Power output measurement

Suppose you want to measure the power output of an audio amplifier. Connect the speaker-output terminals of the amplifier to a load resistor across the vertical-input terminals of the oscilloscope. Hook up a signal generator, set it to 1000 Hz, and connect its output to the input of the amplifier. Now increase the gain of the audio amplifier until the displayed waveform begins to look distorted, and then reduce it until the distortion just disappears. Then, having first calibrated your 'scope to a known voltage as mentioned earlier, you can read the peak-to-peak voltage put out by the amplifier. You then multiply the peak-to-peak value by 0.355 to find the rms voltage, and use the following formula to determine power:

$$P = \frac{E^2}{R} \quad (1)$$

where E is the rms voltage, R is the voice coil impedance (or oad resistance) in ohms, and P is power in watts.

Phase shift

An amplifier is supposed to shift the phase of an input

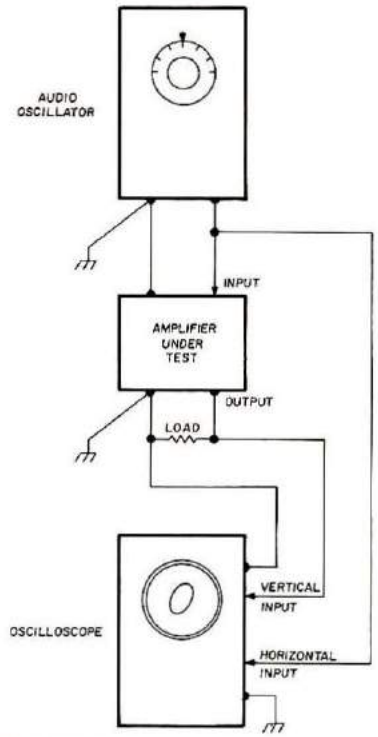
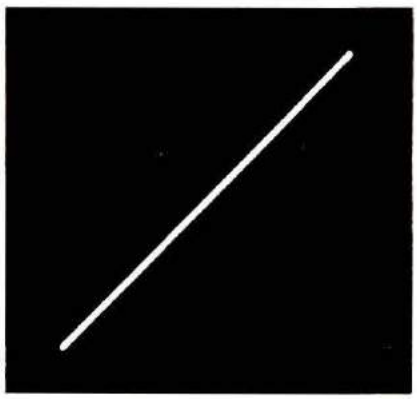
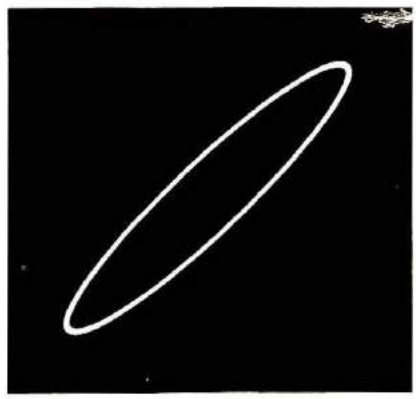


Fig. 3 Block diagram showing the basic connections between an audio oscillator, and audio amplifier and an oscilloscope for the purpose of determining the phase relationship between the signal fed into the amplifier and the amplified output signal.

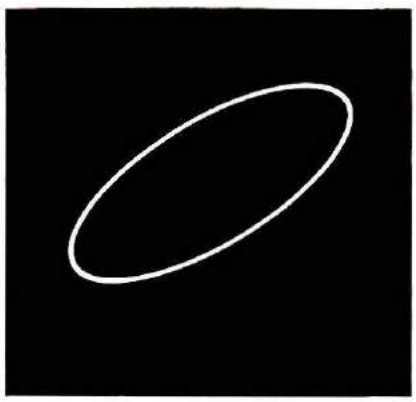
The real value of a oscilloscope becomes apparent when you use it as a diagnostic tool to look inside an ailing electronic circuit.



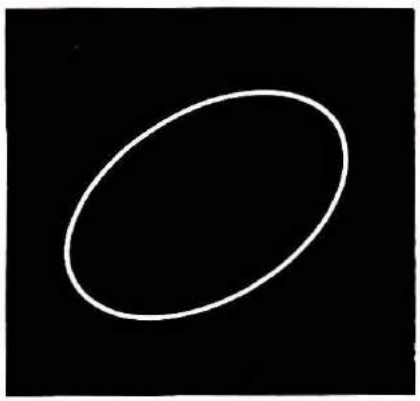
0 degrees (in phase)



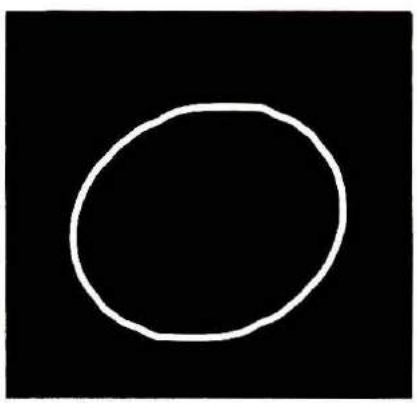
10 to 15 degrees



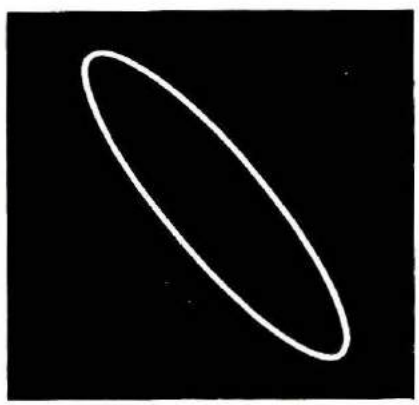
20 to 30 degrees



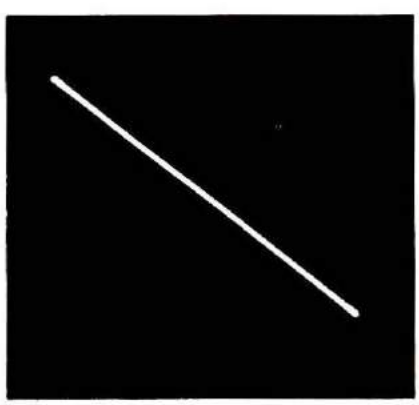
60 to 80 degrees



90 degrees



Approximately 150 degrees



180 degrees

Fig. 4. Illustrates the *Lissajous* patterns obtained with the setup of **Fig. 3** when a variety of phase relationships between input and output signals are displayed on the oscilloscope. In a properly designed and operating amplifier, the relationship should be 180 degrees.

signal by a multiple of 180 degrees, but the actual phase shift may be more or less than this. To determine the input — output phase relationship of a particular amplifier, proceed as follows. Hook up an audio oscillator and an audio frequency amplifier as shown in **Fig. 3**. On the oscilloscope, set the vertical and horizontal amplifier gain controls for the same amount of amplification. Now, vary the frequency of the audio oscillator through the range of frequencies for which the amplifier was designed and compare the patterns you see on the oscilloscope with those shown in **Fig. 4**.

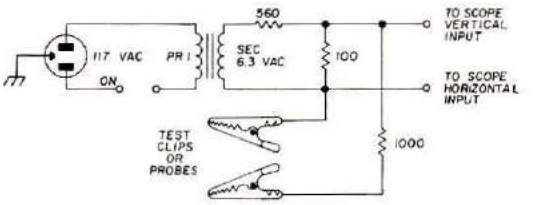
For a permanent record of your amplifier's performance, plot a chart of frequency *vs* phase shift, using graph paper. Lay out values of phase shift from 0 to 180 degrees, using convenient steps of ten or fifteen degrees per increment, along the ordinate (vertical axis), and lay out frequencies, from the lowest to the highest you intend to measure, along the abscissa (horizontal axis) of the paper. Now, by watching the 'scope patterns at any particular frequency in the range you should be able to find the number of degrees of input/output phase shift at that frequency. Make a mark on the graph paper where each of the frequency and phase-shift values intersect. After plotting frequency *vs* phase shift for all the frequencies you are interested in observing, connect the plotted points on the graph to form a smooth curve. At some point, the input/output phase relationship should be 180 degrees. If not, there may be some problems with the amplifier design or its function. In any case, your 'scope will have given you an accurate picture of your amplifier's performance. The abscissa represents zero phase shift.[1]

Audio response measurement

To test an amplifier for audio response, you need a square

Oscilloscopes can be simple or complicated, but don't let the number of knobs and controls scare you. They all fit into one of three categories: one group controls the brightness and focus of what is on the screen; another group controls the speed, timing, and width of scanning in a horizontal direction; and another group controls the gain of the amplifiers for vertical movement of the spot. With a bit of practice, you can use a scope for anything that you would need a volt-ohm-milliammeter for, plus a lot more.

Fig. 6 An auxiliary or "outboard" device that can be attached to an oscilloscope for the purpose of analyzing circuit components such as semiconductors, resistors, capacitors; and shorted or open circuits.

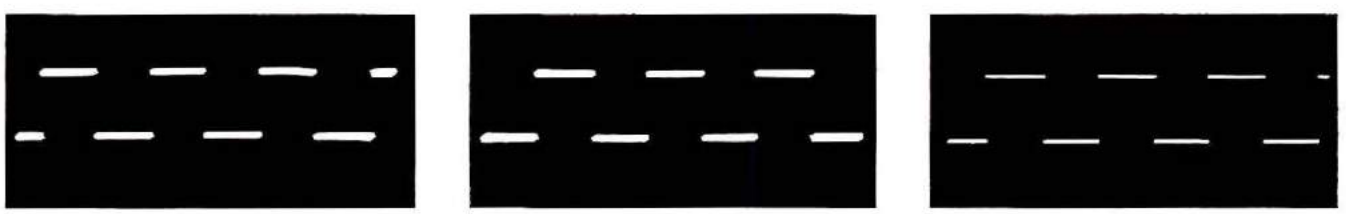


wave generator which is another form of signal generator that produces square waves instead of the sine waves produced by an ordinary audio oscillator. The output of the square wave generator should be connected to input of the amplifier under test. The output of the amplifier is connected to the vertical input terminals of the oscilloscope, as before. Connect the *sweep* terminal of the square wave generator to the horizontal input terminal of the oscilloscope. If the square wave generator has no sweep terminal, then the square wave output signal will also serve as a sweep signal merely by connecting the generator output to the horizontal input terminal of the 'scope. Now observe the patterns on the oscilloscope as you set the square wave generator to several frequencies within the frequency range of the amplifier being tested.

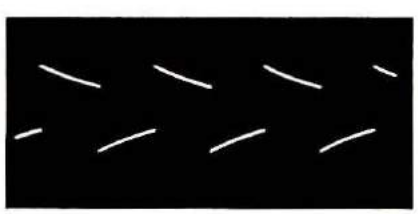
Fig. 5 illustrates the various waveforms, based on square wave forms, obtainable with a simple set up. In a properly operating amplifier, the steep sides show good high-frequency response, and the flat tops indicate good low-frequency response. You can see the waveform from an amplifier having poor low-frequency response, with phase shift, and with poor high-frequency response.

Outboard devices

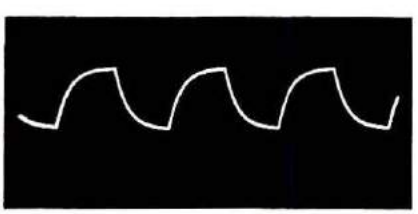
In order to extend the versatility and usefulness of your oscilloscope, there are several outboard devices that you can use to "convert" your 'scope for making other measurements. The device shown in **Fig. 6** is a simple circuit that will allow you to test transistors, diodes, resistors, capacitors, and inductors.[2] It is called a *semiconductor tracer* and "draws" Lissajous figures on the oscilloscope screen. The circuit is very handy for testing semiconductors without removing them from their circuits. For example, a "noisy" semiconductor will produce a very "fuzzy" pattern on the



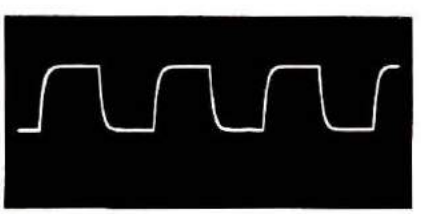
Output from an amplifier having good high-frequency response, indicated by the steep sides of the waveform and good low frequency response indicated by the flat tops of the waveform



Waveform displayed with the amplifier has poor low-frequency response; note the steeply sloping tops on the waveform

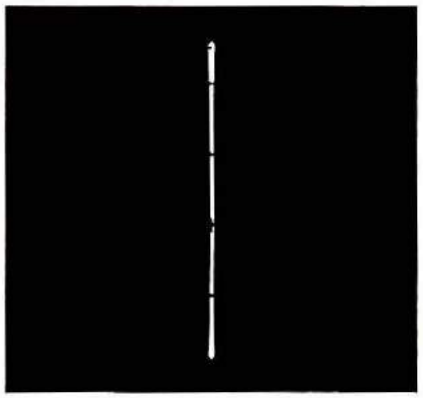


Phase shift, indicated by the square wave pattern distorted toward something that approximates a sine wave

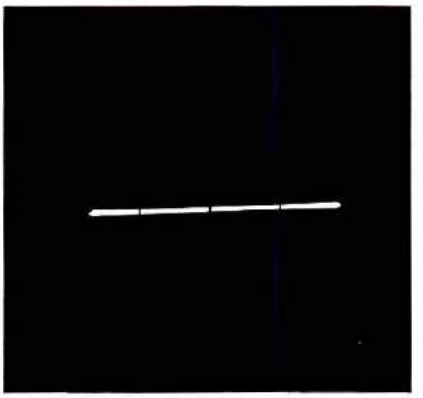


Waveform when high-frequency response is poor; note the rounded corners and sloping sides

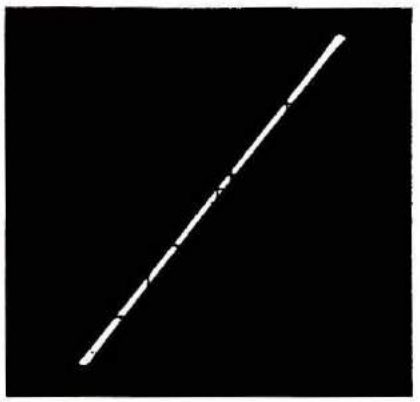
Fig. 5. Variations of a square wave pattern that could be obtained when a square wave oscillator, an audio amplifier and an oscilloscope are used to determine "linearity" of the amplifier's frequency response.



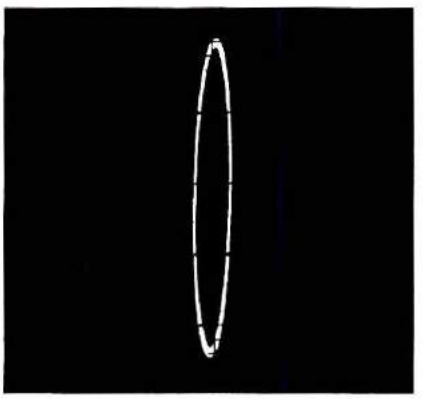
Short circuit or shorted component



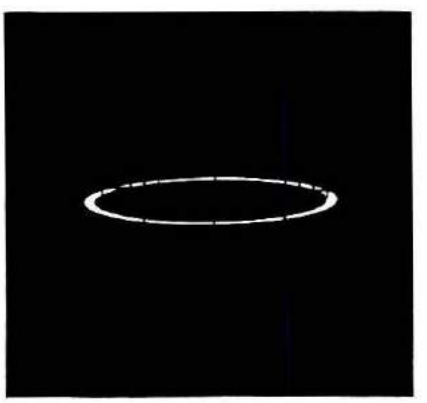
Open circuit or component



Resistance



Inductance



Capacitance

Fig. 7. Typical *Lissajous* patterns obtained using the circuit of **Fig. 6** to analyze various components and circuit conditions.

oscilloscope. **Fig. 7** illustrates a variety of patterns that can be produced by the circuit of **Fig. 6** when its two probes are bridged across the part to be tested. This handy circuit applies only one volt at one milliampere to the semiconductor, ensuring that no damage will be done to it. Circuit components arranged in series or parallel configurations may also be tested with this outboard device.

Monitoring your ssb transmitter

A single-sideband transmitter cannot be completely tested by a meter because a meter cannot follow the complex output waveform produced by the fluctuations of the human voice. To view the output of a ssb transmitter, you need several pieces of test equipment in addition to the oscillator, and a pick-up/tuning unit are needed. ARRL's publication, *The Radio Amateur's Handbook*, gives the necessary information needed to construct and use these pieces of test equipment.[3]

When using your oscilloscope, you should use a shielded cable to reduce hum pickup that will affect the waveform trace. Unfortunately, shielded cable introduces capacitance that often distorts the waveform. Low capacitance probes can be constructed or purchased that will eliminate the problem of capacitance as well as hum pick-up. Although the probe attenuates the signal appreciably, most oscilloscopes have sufficient amplifier gain to increase the signal voltage sufficiently to obtain a viewable display.

Safety and precautions

1. Use shielded leads to all inputs of the oscilloscope. This reduces pick-up of hum and unwanted signals.

2. Do not align a receiver until the oscilloscope and the receiver have had a warm-up time of at least ten minutes. In fact, this is a good rule to remember with any test equipment. Allow enough warm-up time for the equipment to stabilize.

3. Always ground the chassis of the oscilloscope to protect yourself from shock and to reduce the pick-up of stray signals, such as 60- or 120-Hz hum for example, that may be present in the test equipment or in the equipment being tested.

References

1. George Zwick, *The Oscilloscope*, Gernsback Publications, Inc., 1954, page 136.

2. David L. Ludlow, "The Octopus", *QST*, January, 1975, page 40.

3. *The Radio Amateur's Handbook*, American Radio Relay League, Newington, Connecticut, 1976, pages 374, 399.

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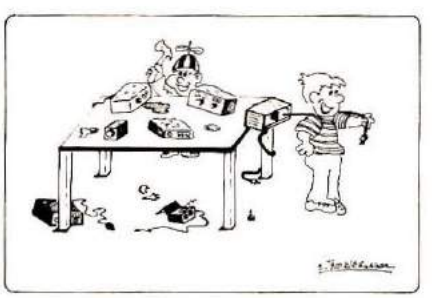

"No daddy don't care if we play in here . . ."